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Variability of Cereal Yields: Sources of Change and Implications for Agricultural Research and Policy

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Many countries have achieved impressive rates of growth in national foodgrain production in recent years. Much of this growth can be attributed to new technologies – especially improved varieties – and the increased use of irrigation and fertilizers. As agricultural output has grown, however, so apparently has its variability, and this presents other problems and concerns that need to be addressed by the agricultural research and policy-making community. This article reviews available evidence on patterns of variability in world cereal production and how these patterns have changed in recent years. The biological, climatic and economic factors underlying yield variability and its changes are discussed and implications sought for both agricultural research and policy.

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Many countries have achieved impressive rates of growth in national foodgrain production in recent years. Much of this growth can be attributed to new technologies, especially improved varieties, and the increased use of irrigation and fertilizers. The increases in production have provided the needed food for many developing countries and have helped to prevent the mass starvation predicted by some observers, while the changes in technology and input use have been, and will continue to be, a feature of modern agriculture.

As agricultural output has grown, however, so apparently has variability, and this presents other problems and concerns that need to be addressed by the agricultural research and policy-making community. Prominent among these concerns are perceptions of increased risk which may make new technologies less attractive to farmers and hence slow agricultural development; and increased instability in national and world food supplies, which may act to destabilize domestic prices, national income and the food consumption of the poor, especially in poor agrarian countries.

This article reviews available evidence on patterns of variability in world cereal production and how these patterns have changed in recent years. The biological, climatic and economic factors underlying yield variability and its changes are discussed, and implications sought for both agricultural research and policy.

Patterns of production variability

Any attempt to measure baseline levels of, or changes in, the variability of cereal production at an aggregate level encounters immediate methodological difficulties:

- Available time series data tend to be short, especially for the eras of modern technology. Results are therefore susceptible to one or two unusual events, or to changes in the definition of periods.
- Time series data contain trends which add to variability when it is

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measured around the mean. It is thus necessary to remove such trends, but this is a fairly subjective process and no single method is ideal: for example, should cyclical fluctuations be viewed as part of the variability or as part of a systematic trend? Results can be sensitive to the functional form chosen for detrending, and whether periods are pooled or detrended separately.

- Available data sources are not always consistent. For many countries, data are available from FAO, USDA and national sources, and sometimes these can give quite different results.[1]
- Methods of data collection within countries sometimes change over time: for example, yield measurements and political boundaries (especially for regions within countries) are occasionally redefined.
- A measure of production variability may not be a relevant measure of risk for decision makers if they are able partially (or fully) to forecast fluctuations each year, and to adjust their resource use correspondingly. Fluctuations should really be measured from expected (anticipated) production rather than from trend. Depending on how expectations and fluctuations are measured, quite different results about changing patterns of production risks can be obtained.[2]
- A statistical measure of variability inevitably has to be chosen. Perhaps the most common measure used is the coefficient of variation (cv), which expresses variability (dispersion captured as standard deviation) relative to the mean. It is a fairly good measure because, if the cv is constant or diminishes over time, the chance of a major shortfall in production below trend will very likely not increase, and any food security 'problem' remains manageable. An absolute measure, such as variance or standard deviation, is a more relevant one for policy makers concerned with the size of grain stocks or with absolute fluctuations in prices.

Notwithstanding such difficulties, what patterns emerge from available data analyses?

Weber and Sievers[3] show that baseline levels of production variability are high in many countries, especially in Africa, the Middle East and Australia. The level of variability is clearly related to climatic factors, and is greatest in semi-arid areas and lowest in humid areas. Southeast Asia has especially low cvs, but North and South America and Europe are also relatively stable. The high cv areas also tend to have low average yields, and have done least well in increasing yields in recent times. Production variability also tends to be greater in small than large countries, because of a lack of risk-pooling effects across regions and perhaps crops.

At the global level, production variability around trend increased between the 1960s and 1970s, as measured by the ratio of the variances ($F = 2.75$) or the value of the cv (from 0.028 to 0.034).[4] The implied probability of a major (say 5%) shortfall below trend in world cereal production also increased (0.035 to 0.068). These changes are real in the sense that they have presented challenges for farmers, consumers and policy makers, but they are not statistically significant at the levels of significance conventionally adopted by scientists. This suggests that there is more reason to believe that the recent decade has been an 'unlucky' sample than that fundamental structural changes in production dictate that future years will be equally or increasingly unstable at the global level. But such aggregate statistical tests do not capture the

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views expressed in this article are the authors' and do not necessarily represent those of the institutions with which they are affiliated.

[1]See, for example, J.C. Flinn and D.P. Garrity, 'Yield stability and modern rice technology', in *Variability in Cereal Yields: Implications for Agricultural Research and Policy*, J.R. Anderson and P.B.R. Hazell, eds, International Food Policy Research Institute, Washington, DC, forthcoming.

[2]See V. Bindlish, R. Barker and T. Mount, 'An analysis of variability in Indian rice yields', in Anderson and Hazell, *op cit*, Ref 1.

[3]A. Weber and M. Sievers, *Instability in World Food Production: Statistical Analysis, Graphical Presentation and Interpretation*, Wissenschaftsverlag Vauk, Kiel, 1985.

[4]P.B.R. Hazell, 'Sources of increased variability in world cereal production since the 1960s', *Journal of Agricultural Economics*, Vol 36, No 2, May 1985.

effects of individual structural changes that are known to have taken place (eg the Green Revolution and increased irrigation), and many individual factors are at work, some of which have a stabilizing effect at the aggregate level, while others are destabilizing. Whether the future will turn out to be more or less variable depends on the particular configuration of structural changes that take place in cereal production, and their combined effects on variability, as well as on the outcome of relevant random variables.

At the global level (excluding China because of data difficulties), the cv of production increased for maize (0.033 to 0.044), barley (0.048 to 0.075) and sorghum (0.052 to 0.057), but decreased slightly for wheat (0.054 to 0.048) and rice (0.039 to 0.038).[5] This suggests that the real impact of the increased instability at the global level may have been in the feed and livestock sectors, although clearly there will have been important exceptions in some of the semi-arid developing areas where coarse grains are important human foods.

Increases in production variability (cv) are not obviously related to baseline levels of variability, or to increases in average production. For instance, when measured across countries, the correlation between the change in average production and the change in the cv is not significant.[6]

The lack of any such simple correlation is due to a complex constellation of factors at work, as illustrated by individual country studies. In the USSR and China, the problem has been less one of increased variability within regions, but rather more one of unbalanced growth between regions that have compensatory relations in production.[7] In Syria, for example, the increase in the cv seems more related to changes in land reform and quota systems than to biological or climatic factors.[8] In Australia, changes in cv seem more directly associated with technological change, especially for spring wheat in the major wheat-producing state of New South Wales.[9]

Patterns of yield variability

Weber and Sievers show that baseline production variability is due primarily to yield variability.[10] Hazell also shows that the increases in the variability of world cereal production since the 1960s (ie contrasting 1960–61 to 1970–71 with 1971–72 to 1982–83) are predominantly due to increases in the variances and covariances of yields.[11] The focus of this paper on yield variability is rationalized on the understanding that it is the major variable of interest in comprehending production variability. It is also a simplifying focus, enabling abstraction from the complexities of variability of areas sown or harvested, which undoubtedly encompass a wider range of economic and policy considerations.

Baseline yield variability follows similar geographic patterns to those for production variability.[12] Many African countries, perhaps in part because of their size, endure some of the highest yield cvs. Yield variability has also increased at the global level (excluding China) since the 1960s; the cv of 'total cereal' yield increased from 0.026 to 0.034, although this change is also not statistically significant at the 5% level.[13]

There have been considerable differences among the changes for individual cereal yields at the global level. The cv of yield decreased for rice (0.033 to 0.026) and millets (0.073 to 0.058), changed little for wheat (0.050 to 0.049) and increased for maize (0.030 to 0.046), barley

[5] *Ibid.*
[6] *Ibid.*
[7] See J.R. Tarrant, 'An analysis of variability in Soviet grain production', and B. Stone and T. Zhong, 'Changing patterns of Chinese cereal production and variability during the People's Republic period', in Anderson and Hazell, *op cit*, Ref 1.
[8] H. Nguyen, 'Agricultural planning policy and the variability of Syrian cereal production since the 1970s', in Anderson and Hazell, *op cit*, Ref 1.
[9] J.R. Anderson, J.L. Dillon, A.J. Cowie, P.B.R. Hazell and G.H. Wan, 'Changing variability in cereal production in Australia', *Review of Marketing and Agricultural Economics*, forthcoming.
[10] Weber and Sievers, *op cit*, Ref 3.
[11] Hazell, *op cit*, Ref 4.
[12] Weber and Sievers, *op cit*, Ref 3.
[13] P.B.R. Hazell, 'Introduction', in *Summary Proceedings of a Workshop on Cereal Yield Variability*, P.B.R. Hazell, ed, International Food Policy Research Institute, Washington, DC, 1986.

(0.043 to 0.064) and sorghum (0.040 to 0.046).[14] These differences may largely reflect differences in the variability of the conditions under which the crops are grown. The fact that so much rice is grown intensively with irrigation or deep bunding probably accounts for that crop having some of the lowest cvs of yield in both periods. Analogously, an increasing proportion of the world's wheat crop is grown under irrigation and with high levels of purchased inputs. At the other end of the scale are the millets, typically grown under marginal conditions of low and variable rainfall. There is a tendency in many arid regions for maize to displace sorghum, and for sorghum to displace millet in the least favourable environments. Barley likewise may be 'pushed' by wheat into more marginal environments, and this could account for the rise in its cv.[15]

Yields tend to be more highly correlated between adjacent regions and countries because of common climatic factors.[16] However, they have also become more positively correlated between crops and countries since the 1960s,[17] between regions within countries[18] and between farms.[19] These increased correlations have been a major factor contributing to increased variability in national yields in some countries, as well as at the global level. Country data do not suggest any strong relationship between increased cvs for yields and the growth in average yields.[20]

In Bavaria and England, wheat yields have increased impressively in recent decades, yet the cvs have changed little.[21] Indeed, the cv of wheat yields has not changed substantially in England since the early 1800s. This stability is probably attributable to the relatively stable and temperate climate of the two countries, and the intensive and continually improving standards of management. In contrast, the cv of wheat yields has increased in New South Wales, Australia, since the introduction of semi-dwarf varieties and the sharp rise in average yields that they seemingly induced.[22] The difference may lie with the much more variable climate and the extensive management practices (eg only rather unchanging amounts of superphosphate are used). Walker also found that the cvs of sorghum and millet yields have increased in the semi-arid areas of India since the introduction of high-yielding varieties (HYVs).[23] These contrasting experiences suggest that yield increases in the semi-arid areas are more likely to be accompanied by increases in variability (cv) than are yield increases in more humid areas. Differences in management intensity are likely to accentuate these contrasts.

Sources of yield variability

Yield variability is determined by variety (genotype), variability and level of agronomic inputs (fertilizers, irrigation, pesticides, etc) and variability in pest, disease and climatic factors (rainfall, frosts, temperature, etc). Interactions between these factors are important although difficult to analyse, especially between variety and other factors.

Variety and yield variability

Under controlled (especially in field trial) conditions, modern varieties typically have higher mean yields and variances than unimproved varieties, but their cvs are either lower or about the same. Recent evidence is available for winter wheat in the US Great Plains, millets in India and winter wheat and spring barley in Bavaria.[24] Similar results

[14] *Ibid.*
[15] See, for example, G. Fischbeck, 'Trends in yield increase and yield variability of winter wheat and spring barley in Bavaria', abstract in Hazell, *op cit*, Ref 13, and Nguyen, *op cit*, Ref 8.
[16] Weber and Sievers, *op cit*, Ref 3.
[17] Hazell, *op cit*, Ref 4.
[18] See P.B.R. Hazell, 'Sources of increased instability in Indian and U.S. cereal production', *American Journal of Agricultural Economics*, Vol 66, No 3, Aug 1984. Also, J.B. French and J.C. Headley, 'Variability in maize and wheat yield as influenced by technology and weather in the U.S., 1931–81', and T.S. Walker, 'HYVs and instability in sorghum and pearl millet production in India', both in Anderson and Hazell, *op cit*, Ref 1.
[19] J.P.G. Webster and N.T. Williams, 'Changes in the variability of wheat and barley production in southeast England since 1964', in Anderson and Hazell, *op cit*, Ref 1.
[20] P.B.R. Hazell, 'Changing patterns of variability in world cereal production', in Anderson and Hazell, *op cit*, Ref 1.
[21] R.B. Austin and M.H. Arnold, 'Variability of wheat yields in the U.K.: analysis and future prospects', in Anderson and Hazell, *op cit*, Ref 1. Also, G. Fischbeck, *op cit*, Ref 15.
[22] Anderson *et al*, *op cit*, Ref 9.
[23] Walker, *op cit*, Ref 18.
[24] C.J. Peterson, V.A. Johnson, J.W. Schmidt and R.F. Mumm, 'Contributions of genetic improvement to increases in wheat yields and variance of productivity in the Great Plains', abstract in Hazell, *op cit*, Ref 13, Walker, *op cit*, Ref 18, and Fischbeck, *op cit*, Ref 15.

seem to hold in farmer-managed trials, as shown for upland rice in the Philippines and for wheat and rice in India.[25] CIMMYT varieties of wheat and maize also seem to be more stable than available alternatives under experimental conditions when their performance across contrasting sites (environments) is compared.[26]

These favourable results reflect the ability of plant breeders to select genotypes that combine high yield performance with stability. Some of the elements of genetic improvement are as follows:

- *Adaptability*. Shortening of the life cycle of cereal crops and reduction of their sensitivity to seasonal signals such as daylength allows crops to perform more evenly across a range of sites, latitudes and climates, thereby increasing their adaptability. So too does wider tolerance of soil conditions.
- *Hardiness*. Another important source of improvement has been in the ability to withstand drought, cold, heat or other climatic insults, especially at the most sensitive stages of the life cycle. Such hardiness is sometimes highly specific, sometimes more general. Specific resistance to extremes of heat or cold has been improved in many crops (eg of rice and millet in Japan to cold) and, although the changes may seem small in a physiological sense, they may be of considerable significance in reducing downside variability. Hybrids may exhibit a more general hardiness in that, although they may be no more productive than inbreds under optimal conditions, they may perform substantially better than their parents at both high and low temperatures.[27]
- *Reduced vulnerability*. Reducing the vulnerability to pests and diseases, through the incorporation of genetic resistance – wide or narrow – to their current biotypes is a major preoccupation of plant breeders and a major contribution towards yield stability. In general, it has been easier to achieve than resistance to climatic stresses.
- *Responsiveness*. On top of these characteristics there is the desirability of enhancing the ability of a variety to give a return on favourable conditions or higher inputs with greater yield or quality.
- *Competitiveness*. This is another desirable characteristic, especially in marginal environments or where weed problems are serious.

All of these characteristics can influence the variability of yield; responsiveness, especially on the upside, hardiness and reduced vulnerability on the downside. However, they are not always compatible with one another, and trade-offs between them often must be made by the plant breeder, eg between hardiness and responsiveness or, especially in the case of tall versus dwarf selections, between competitiveness and responsiveness.

The claimed stability of modern varieties is not always reflected in farm, regional or national yield data. There are a number of reasons for this. First, some of the early modern varieties associated with the international agricultural research centres proved to be susceptible to particular pests and diseases. Because of their high yields, these varieties were widely adopted in a very short time and when pest and disease outbreaks occurred, these had a sizable negative impact on farm and aggregate yields. This problem has been contained in recent years by the availability of a greater range of modern varieties, many of which have a wider range of resistance to pests and diseases.[28] Continuing

[25] J.C. Flinn and D.P. Garrity, 'Yield stability and modern rice technology', in Anderson and Hazell, *op cit*, Ref 1; and M. Mruthyunjaya and D. Jha, 'A note on the impact of varietal improvement and intercropping on variability of cereal yields', abstract in Hazell, *op cit*, Ref 13.

[26] W.H. Pfeiffer and H.J. Braun, 'Yield stability in bread wheat', and H.N. Pham, S.R. Waddington and J. Crossa, 'Yield stability of improved germplasm developed and distributed by the CIMMYT maize program', both in Anderson and Hazell, *op cit*, Ref 1.

[27] J.R. McWilliam and J.B. Griffing, 'Temperature-dependent heterosis in maize', *Australian Journal of Biological Sciences*, Vol 18, No 3, 1965; and J.R. McWilliam, B.D.H. Latter and J.J. Mathison, 'Enhanced heterosis and stability in the growth of an interspecific *Phalaris* hybrid at high temperature', *Australian Journal of Biological Science*, Vol 22, No 3, 1969.

[28] W.R. Coffman and T.R. Hargrove, 'Modern rice varieties as a possible factor in production variability', and D.N. Duvick, 'Possible genetic causes of increased variability in U.S. maize yields', both in Anderson and Hazell, *op cit*, Ref 1. Also, J.H. Holden, 'Genetic aspects of yield variability', in Hazell, *op cit*, Ref 13.

strong emphasis is given to 'maintenance' research, whereby replacement varieties are developed and kept in reserve. Pest and disease resistance breeding is now so sophisticated that the more rapid turnover of varieties in time has effectively substituted for the larger number of traditional varieties used at any one time.

Another reason why observed yield variability may increase with the introduction of modern varieties lies in their greater responsiveness to modern inputs. Some modern varieties seem to perform about as well as traditional varieties in poorer environments, or under low input conditions, but their yields are much higher under favourable conditions and with greater application of inputs.[29] Consequently, if farmers adjust input use from year to year in response to changes in price signals or in response to limited supplies of inputs, this may induce a much higher degree of yield variability in modern varieties. Such behaviourally induced yield variability may have become an important factor in some countries, particularly in developing countries where the greatly increased demand for the inputs that accompanied the Green Revolution outstripped the possibilities for adequate and timely supplies, given limited infrastructure and foreign exchange shortages.[30] The problem may also have been aggravated by the sharp increases in the cost of fertilizers and other agrichemicals that accompanied the oil crises of the 1970s, and by an increasee in the variability of cereal prices in world markets.

A further reason why aggregate yields may have become more variable with the introduction of modern varieties is the increased correlations among yields between farms (and regions). This again may be due to variations in input use, since farmers in the same or adjacent regions are likely to face the same prices and input shortages, thereby making similar adjustments in their use of inputs. The increased correlations may also be related to varietal choice. By screening for genotypes that perform well in many locations at the same time, breeders may inadvertently be increasing the chances of greater yield correlation between locations, and hence between farms and regions. This need not be a problem for farmers, but it can add to the variability of national yields.

The widespread adoption of a few varieties may also lead to increased correlations through a common susceptibility to pests and diseases, and a common responsiveness to weather conditions. This problem may have been aggravated by more homogeneous cultural practices and by an increased dependence on purchased inputs,[31] but whereas synchronization of the crops in a region may make them all susceptible to extremes of heat, cold or drought at particular stages, they may also spread the risk of losses from birds or rodents, as with rice crops in Asia.

It is also true that many modern varieties bring together a wider range of genotypes into their ancestry than traditional varieties and are better able to cope with a wide range of climatic and pest problems.[32]

Climatic factors

A major source of yield variance in all cases, but especially for the cereals grown in more arid areas, is the variability in crop weather. Carter and Parry conclude, however, that there is no indication that recent changes in cereal yield variability can be ascribed to climatic change.[33] If anything, weather in some areas may have become less variable, eg in the US Cornbelt.

[29]Pfeiffer and Braun, *op cit*, Ref 26. Also, Pham, Waddington and Crossa, *op cit*, Ref 26.
[30]H.K. Jain, M. Dagg and T.A. Taylor, 'Yield variability and the transition to the new technology', in Hazell, *op cit*, Ref 13.
[31]Duvick, *op cit*, Ref 28.
[32]Holden, *op cit*, Ref 28.
[33]T. Carter and M. Parry, 'Climatic change and changes in crop yield variability', in Hazell, *op cit*, Ref 13.

Inter-annual variations – such as those associated with the El Nino/Southern Oscillation phenomenon or with the sub-Saharan droughts of 1972, 1977 and 1983–84 – have certainly influenced global cereal production and variability, but there is probably a need to look elsewhere for the causal factors of changes in variance and covariance in recent years, even though long-term climatic changes associated with rising atmospheric carbon dioxide levels are likely to have important implications for cereal production in the future.

Agronomic inputs

Under trial conditions, the more intensive use of purchased inputs seems to be associated with increases in the mean and variance of yields, but with little or no change in the cv. For example, with nitrogenous fertilizer application to wheat and barley in Germany, Hanus and Schoop found that the cv actually declined with heavier applications until the yield asymptote was approached.[34] The cv then increased sharply at higher rates of application as diseases increased, but could successfully be reduced by the application of fungicides. McIntire and Fussell also found that fertilizer use reduces the cv of yields for local millet cultivars in Niger.[35] In contrast, Roumasset and co-workers report that nitrogen tends to increase yield variability both absolutely and relatively on irrigated rice in the Philippines.[36]

Conflicting forces may be at work in the changes in yield variability under farm conditions as agriculture becomes more intensive. On the one hand, variability tends to fall as agronomic control of the environment becomes more complete, as in the case of wheat in Western Europe. On the other hand, selection for higher yield potential is dependent on enhanced agronomic support for the crop and, when this is unreliable, the higher yielding varieties may be vulnerable to greater variation. The latter may be particularly true during the early stages of more widespread and heavier use of a particular input, but then falls as its use becomes more uniform and as its rate of application approaches the response asymptote. With irrigation, for example, Mehra[37] found that variability had fallen as tubewell irrigation of wheat crops in the Punjab became more extensive but, with rice in the Philippines for contrast, while wet season crops were less variable, the limited, uneven and unreliable irrigation of dry-season crops may increase variability.[38]

In general, there may be considerable scope for the reduction of variability by more flexible, better informed and more diversified and specific use of inputs. This will not, however, always be consistent with reducing inter-regional yield correlations. Pandey provides evidence that irrigation that is stabilizing at the local level may increase correlations, thereby having a mixed effect on variability at aggregate levels.[39] Webster and Williams also suggest that the recent but widespread adoption of fungicides on wheat in Southeast England may be a major contributor of increased inter-farm yield correlations.[40]

Consequences of increased variability in cereal yields

Variability in yields, as well as any increases in such variability, can have important economic and welfare consequences, especially for farmers and poor consumers. We briefly review these consequences as a prelude to discussion of policy options.

[34]H. Hanus and P. Schoop, 'Influence of nitrogen fertilizing and fungicide treatments on yield and yield variability of wheat and barley', in Anderson and Hazell, *op cit*, Ref 1.

[35]J. McIntire and L.K. Fussell, 'Components of millet yield variance and their research implications', in Anderson and Hazell, *op cit*, Ref 1.

[36]J.A. Roumasset, M. Rosegrant, O. Chakravarty and J.R. Anderson, 'Fertilizer and crop yield variability: a review', in Anderson and Hazell, *op cit*, Ref 1.

[37]S. Mehra, *Instability in Indian Agriculture in the Context of the New Technology*, Research Report 25, International Food Policy Research Institute, Washington, DC, 1981.

[38]M.W. Rosegrant, 'The impact of irrigation on area, yield and income variability: a simulation analysis', abstract in Hazell, *op cit*, Ref 13.

[39]S. Pandey, 'Effects of irrigation on variability of cereal grain production', in Anderson and Hazell, *op cit*, Ref 1.

[40]Webster and Williams, *op cit*, Ref 19.

Although data limitations are such as to make it difficult to be explicit in most cases, the fundamental issue facing decision makers is the cost-effectiveness of coping with variability. The ways of coping are diverse, from storage of, trade in and stabilization schemes for the commodities, to insurance, credit and compensatory finance arrangements. These are not costless, yet neither are the other major alternatives to coping, namely ways of reducing variability, through diversification, infrastructure improvements including irrigation, and more stable productivity through such means as improved cultural practices and plant breeding. Reducing variability will only be worth while if it can be achieved more economically than can better ways of coping with it.

Consequences for farmers

Increased yield risks associated with improved varieties or new technologies may hinder their widespread adoption by farmers, thereby limiting growth in national food supplies. There is ample empirical evidence to show that most farmers act in risk-averse ways when making resource allocation decisions that affect their income.[41] However, studies of the relationship between yield risks and the adoption of specific varieties or technologies show mixed results, probably because of the different types of technologies and farming systems studied (eg irrigated versus rainfed agriculture).[42] There are still too few studies using comparable methods to permit useful cross-study analyses, but the conflicting results may also reflect the complexity of the relationship between yield risks and the variability of farm or family income. Since it is presumably the stability of income (or family consumption) that concerns farmers most, increased yield risks should only be a problem if they lead to greater instability in income.

Yield risks are only some of many risks that affect a farmer's income, and some of these risks may act to offset each other. Within a crop, higher yield risks may be partly offset by negatively correlated fluctuations in prices, and the return from the crop may be much more stable than the variability of prices and yields considered separately would suggest. When more than one crop is grown, there is also scope for low or even negative correlations between the returns of the different crops, with a resultant stabilizing effect on aggregate income. Walker and Jodha have shown that small-scale farmers in dryland India can be surprisingly efficient in reducing income risks through a variety of cultural practices (intercropping, spatial diversification, staggered planting dates, etc), through off-farm employment, use of credit and by participating in land leasing arrangements which effectively share some of the yield risks with landlords.[43] Within this rather complex framework, few generalities about the relationship between yield risks for individual cereals and the stability of family income seem likely to emerge.

Consequences for poor consumers

In principle, one would expect high production years for major cereals to be good for poor consumers. They should gain from more plentiful food supplies, from lower prices and perhaps from increased agricultural employment. The opposite might be expected in low production years. However, as in the case of farm incomes, things can be more complex than this. Since consumers typically purchase a number of

[41] See, for example, H.P. Binswanger, 'Attitudes toward risk: experimental measurement in rural India', *American Journal of Agricultural Economics*, Vol 62, No 3, 1980.

[42] Studies showing that risk was not a significant impediment to the adoption of new technologies include: T.S. Walker, 'Risk and adoption of hybrid maize in El Salvador', *Food Research Institute Studies*, Vol 18, No 1, 1981; J.A. Roumasset, *Rice and Risk: Decision Making Among Low Income Farmers*, North-Holland, Amsterdam, 1976; and G. O'Mara, 'The microeconomics of technique adoption by smallholding Mexican farmers', in *The Book of CHAC: Programming Studies for Mexican Agriculture*, R.D. Norton and L. Solis, eds, Johns Hopkins University Press, Baltimore, MD, 1983. Contrasting studies include Binswanger, *op cit*, Ref 41, and E.R. Moscardi and A. de Janvry, 'Attitudes toward risk among peasants: an econometric approach', *American Journal of Agricultural Economics*, Vol 59, No 4, 1977.

[43] T.S. Walker and N.S. Jodha, 'How small farm households adapt to risk', in *Crop Insurance for Agricultural Development: Issues and Experience*, P. Hazell, C. Pomareda and A. Valdes, eds, Johns Hopkins University Press, Baltimore, MA, 1986.

different food crops, shortages or high prices for one may simply be offset by substituting other foods whose supplies are more plentiful or whose prices are lower. There is a surprising lack of evidence on the relationship between the variability of individual food supplies and the instability of the incomes and nutritional intake of the poor.

Sahn and von Braun have mustered most of this evidence and show that production variability does not necessarily translate into national food insecurity problems.[44] Many governments do seem to take effective action through storage and trade policies to dampen fluctuations in domestic consumption, and consumers substitute between foods in response to their relative scarcities. However, Sahn and von Braun did not include any of the smaller semi-arid countries of Africa in their study, and recent experience suggests that extended droughts, in conjunction with inadequate famine policy response, can have devastating effects on food consumption in those countries. Further, even in countries where aggregate food consumption is relatively stable, the consumption of some of the poorer households can still be at risk, particularly when their incomes are tied to agricultural production (eg smaller farmers and landless workers). Food security problems therefore continue to be a problem in many developing countries, even where the cv of aggregate production has not increased to aggravate the problem.

Implications for agricultural research

What can be done through technological approaches to reduce yield variability and yield correlations?

Plant breeding and crop improvement

Plant breeders have long recognized the importance of selecting 'stable' varieties. They have achieved, especially for wheat and rice but also in many other crops, significant gains in adaptability, hardiness to extreme conditions and reduced vulnerability to pests and diseases, but the gains in stability components may be compromised by selection for responsiveness. As Arnold and Austin note, plant breeders may be seeking several different things under the broad objective of stability.[45]

Several problems are implicit in the time-consuming assessment of varietal stability. One is that varieties may have only relatively short useful lives after such assessments are completed. This has led breeders to rely on measuring yield variations across sites as a proxy for yield stability over time at specific locations. The evidence for the reliability of this approach is not particularly encouraging.[46] Further, the Yates and Cochran, the Finlay and Wilkinson and the Eberhart and Russell method of analysis,[47] although convenient and widely used by breeders, can be misleading, especially when only the regressions, not the data points, are given. It is too open to the selective presentation of data, it can obscure valuable site-specific adaptation and it tends to be rather unhelpful at the low mean yield sites more characteristic of on-farm conditions. Moreover, the regression slope is not a fixed varietal characteristic, as shown by Peterson and co-workers, for Kharkov wheat, where it had fallen progressively over the years as the responsiveness of new varietal entries has risen.[48] It is clearly time that other forms of data assessment, such as multivariate and cluster analysis and stochastic dominance, are explored to overcome these failings.[49]

[44]D.E. Sahn and J. von Braun, 'The consequences of increased variability in food production on income, consumption, and food security', in Anderson and Hazell, *op cit*, Ref 1.

[45]M.H. Arnold and R.B. Austin, 'Plant breeding and yield stability', in Anderson and Hazell, *op cit*, Ref 1.

[46]See, for example, W.D. Watson and J.R. Anderson, 'Spatial versus time-series data for assessing response risk', *Review of Marketing and Agricultural Economics*, Vol 45, No 3, 1977. Also, R.E. Evenson, J.C. O'Toole, R.W. Herdt, W.R. Coffman and H.E. Kauffman, 'Risk and uncertainty as factors in crop improvement research', *IRRI Research Paper Series 15*, International Rice Research Institute, Manila, Philippines, 1978.

[47]The standard references are: F. Yates and W.G. Cochran, 'The analysis of groups of experiments', *Journal of Agricultural Science*, Vol 28, No 4, 1938; K.W. Finlay and G.N. Wilkinson, The analysis of adaptation in a plant breeding program', *Australian Journal of Agricultural Research*, Vol 14, No 6, 1963; S.A. Eberhart and W.A. Russell, 'Stability parameters for comparing varieties', *Crop Science*, Vol 6, No 1, 1966.

[48]Peterson *et al*, *cp cit*, Ref 24.

[49]See Arnold and Austin, *op cit*, Ref 45, and J.R. Witcombe, 'The variability in the yields of pearl millet varieties and hybrids in India and Pakistan', in Anderson and Hazell, *op cit*, Ref 1. Also H.P. Binswanger and B.C. Barah, *Yield Risk, Risk Aversion and Genotype Selection: Conceptual Issues and Approaches*, ICRISAT, Research Bulletin 3, Patancheru, 1980.

Recent and contemporary plant breeding is seemingly not explicitly addressing the yield correlation 'problem' and may, in fact, be increasing correlations by more-or-less routinely screening for genotypes that perform well in many locations at the same time. More localized breeding endeavours, with more of the selection effort based on performance under more specific agro-ecological conditions, might help to reduce inter-regional correlations while also improving performance in farmers' fields. But this would involve somewhat greater expenditures for agricultural research, depending on the extent of agro-ecological diversity.

Breeding for marginal conditions

There is less agreement about breeding for the most marginal, lowest yielding sites. Varietal improvement under these conditions is difficult and will be slower, less certain and more costly in terms of plant breeding effort. But it can be achieved, as examples for most of the cereals indicate. Improved tolerance for drought and heat stresses (eg in US maize hybrids), greater tolerance of adverse soil conditions (eg International Rice Research Institute (IRRI) rice varieties), more efficient performance at low nutrient levels (eg Mahsuri rice), resistance to *Striga* or downy mildew, and many other characteristics, have already improved cereal performance under poor conditions. Even when the improvement is small, it may have a substantial impact on adoption, eg of finger millets in India.

Yet various factors tend to minimize plant breeding work for poor environments. Gains are less spectacular and may be seen as less rewarding and as having less impact on the variability of cereal production. Many farm conditions may be even poorer than the poorest experimental test sites, and conditions may also be inherently more variable and diverse, leading to greater site specificity. Government policies for varietal testing and release may also discourage such work, as may policies restricting the allocation of fertilizers to such areas.

Genetic vulnerability

The extent to which the genetic base of modern cereal varieties and hybrids influences the downside risks is difficult to assess. Outbreaks of pests and diseases have had an impact, sometimes disastrous, throughout recorded history. Problems still occur, for example with downy mildew on millet in India, but major disasters, such as the earlier stem rust epidemics in North American wheat crops, have been contained in recent years. Southern corn leaf blight on T-cytoplasm maize hybrids was pandemic in the USA in 1970 but, within a year, the genetic base was changed enough to deal with the pathogen. Other problems loom as possible threats, such as the failure of brown plant hopper biotype 2 resistance in IR36 rice, or of leaf rust resistance in some CIMMYT varieties, or the widespread cytoplasmic uniformity of IRRI rice varieties or of hybrid rice in China, but replacement varieties are already in reserve.

However, the fact that several wheat and rice varieties, such as Bezostaia wheat in Eastern Europe and IR36 rice in Asia, have been grown on more than 10 million ha each, inevitably means that their sudden failure would raise the covariance in yield, as could their similar response to weather conditions common to a large region. This element of covariance would decline in the future if plant breeding – whether

public, private or in the international research centres – were to evolve towards greater emphasis on regional and local adaptation. Greater diversity in varietal use might also be achieved through more consistent seed multiplication and release policies, particularly where these are under public control.

Beyond plant breeding

Agronomic inputs are as significant as genotype to cereal production and stability, yet they often receive far less attention in agricultural research institutes. In general, there may be considerable scope for the reduction of variability by more flexible, better informed, and more diversified and specific use of inputs. As Carlson has emphasized,[50] farmers may have real informational problems when adjusting to new input-responsive crops or varieties. Their previously accumulated knowledge about yield responses suddenly becomes redundant, and new knowledge has to be acquired, especially about appropriate input strategies in the event of drought or pest attacks. This information needs to be made available on a timely basis through the agricultural research and extension systems.

Some management practices, such as intercropping, spatial diversification and staggered planting, may also be helpful in reducing yield losses in farmers' fields, although how efficiently or at what cost is an issue deserving greater attention in farming systems research.

Implications for agricultural policy

Rural societies have been contending with variability of production of their basic staples for millennia. The difficulties associated with this reality are probably tending to increase in many parts of the world, if, as is shown herein for several regions, variability and riskiness of productivity are increasing and, with rapid population growth, greater numbers of people are affected. This tendency is more than compensated for in most parts by the moderating influences of better transport and trading systems and the improved policies and responses that these have made possible.

In considering the various possibilities for intervention, caution is called for in not aggravating the situation by, perhaps unwittingly, making it more difficult for households to cope. The credit market is one case in point. Resource-poor farmers use a variety of informal adjustments to deal with variability, including participation in various credit markets. Intervention by governments in credit markets often has the effect of making the risk management of such farmers less effective than it would otherwise be.[51] Clearly, there is a role for authorities to enrich the mix of credit availabilities, but any regulatory role needs to be exercised sensitively, with good understanding of the needs of participants who face possibly extreme levels of downside risk.

Another danger is that government policies may cause or exacerbate poor decision-making with respect to both investment and resource allocation in areas that are suffering long-term climatic or ecological problems. Intervention should be couched in such a manner as not to shield individual decision makers from reality, whatever that may be and whatever processes of change in either the natural, economic or social environment may be under way.

Related to the possibility of interventions discouraging appropriate

[50]G.A. Carlson, 'Rice production variability: the role of pest resistant varieties and other inputs', in Anderson and Hazell, *op cit*, Ref 1.
[51]Walker and Jodha, *op cit*, Ref 43.

learning, is the exacerbation of uncertainties faced by farmers. There is relatively little analytical attention addressed to this, but the pioneering works of MacLaren on the effects of policy uncertainty are instructive and perceptive.[52] Policy-induced risks may add to the decision-making burden of affected individuals – even when policies have the stated objective of modifying or mitigating risks. For example, in the USA, Wilhite and co-workers found that government reaction to drought crises was generally *ad hoc* and often resulted in the implementation of hastily prepared assessment and response procedures that in turn gave ineffective and poorly coordinated results.[53] The difficulties related in part to the multitude of agencies involved in administration and to the diversity of procedures and criteria used by such agencies. Much the same situation has prevailed in Australia.[54]

Crop insurance

In principle, crop insurance is an attractive way of helping farmers cope with yield risks, especially where the risk of catastrophic losses is high. Unfortunately, past experience with crop insurance is not encouraging, and the costs of publicly provided insurance have usually far exceeded their benefits.[55] Nor should the efficiency with which farmers and traditional village institutions cope with risks be neglected. Walker and Jodha have provided cogent information on these issues, and they point out that crop insurance might sometimes simply provide a more costly substitute for existing private risk-sharing arrangements.[56] Improvement of financial institutions might be a viable approach, particularly if these involve an expansion of medium-term consumer credit so that farmers can more readily borrow money in bad years and pay it back in good years.

The possibility of an insurance market addressed to random environmental driving forces such as rainfall is somewhat more promising than direct insurance of crops. There have been some experiments with rainfall insurance and, indeed, this matter is being carefully assessed in the Australian context. If there is a reliable meteorological service upon which such a scheme can be based, at least the problem of 'moral hazard' is solved. Similarly, if the scheme is well designed there may be relatively few difficulties associated with adverse selection. Administration costs can, accordingly, be kept relatively low and such an insurance scheme may well prove to be widely applicable, attractive to farmers and commercially viable. However, the fact that few, if any, such schemes have arisen spontaneously must call their inherent viability into question. The explanations probably lie in the imperfections of rainfall insurance as a risk-bearing device, including non-uniform distribution of rainfall over administrative domains, the lack of correspondence between simple temporal aggregates of rainfall and realized crop yields, and the elements of farmers' uncertainty that are little influenced by rainfall experience.

Marketing systems

For mitigating farm-level risk, the more that individual farmers can link with the rest of the world in their economic realizations, the more they can exploit society at large for self-insurance. Effective marketing systems for farm inputs and outputs must be seen as a necessary condition for improving the opportunities of rainfed farmers to manage their risks. Just as for financial institutions, marketing systems by their

[52]D. MacLaren, 'Agricultural policy uncertainty and the risk averse firm', *European Review of Agricultural Economics*, Vol 7, No 4, 1980. See also 'The output response of the risk averse firm: some comparative statics for agricultural policy', *Journal of Agricultural Economics*, Vol 27, No 3, 1983.

[53]D.A. Wilhite, N.J. Rosenberg and M.H. Glantz, *Government Response to Drought in the United States – Lessons from the mid-1970s*, Climate Dynamics Program, Final Report of NSF Grant No ATM-8108447, National Center for Atmospheric Research, Boulder, CO, 1982.

[54]See J.R. Anderson, 'Impacts of climatic variability in Australian agriculture: a review', *Review of Marketing and Agricultural Economics*, Vol 47, No 3, 1979, and J.W. Freebairn, 'Drought assistance policy', *Australian Journal of Agricultural Economics*, Vol 27, No 3, 1983.

[55]For a recent review of past experience, see P. Hazell, C. Pomareda and A. Valdes, *Crop Insurance for Agricultural Development: Issues and Experience*, Johns Hopkins University Press, Baltimore, MD, 1986.

[56]Walker and Jodha, *op cit*, Ref 43.

very nature are generally expected to work best when unregulated so that buyers and sellers are unconstrained and can interact freely.

The concept of marketing systems in this context is broad, ranging over availability of physical space and entrepreneurial operators, the provision of effective financial institutions, and transportation infrastructure and facilities. The systems must feature flexibility to function in highly variable environments which may well switch from being net exporters to net importers from season to season. Physical access to markets on a continuing basis via adequate road and other transport facilities is a strong advantage in meeting seasonal contingencies, whether they be of a favourable or unfavourable nature.

Improvement of marketing systems will generally feature under whatever development approach is followed. It is some consolation for planners to know that they will also be mitigating the risks faced by most farmers if they can be successful in improving the effectiveness of the marketing system at large.

Buffer stocks and price stabilization

At the national level, increased variability in prices and food consumption can be contained through buffer stock schemes. However, Siamwalla and Valdes argue that, in most cases, it is more cost-effective for governments to use world markets to stabilize domestic consumption, sometimes using the IMF food facility as a source of funding for food imports when appropriate.[57] Interventions can also be targeted on specific socioeconomic groups, such as food subsidies for the poor, or on relief employment and food-for-work schemes. The efficiency of these and other direct interventions is elaborated on by Sahn and von Braun.[58]

In terms of farm-level risk mitigation, the major disadvantage of commodity price stabilization is that farmers are not so much concerned with price variability as with income variability. Stabilizing prices may even lead to increased income variability. This possibility is likely if price and yield are negatively correlated, or if farmers grow several crops whose returns, though individually unstable, are collectively relatively stable. There may also be situations where price risk is not particularly important. Further, as discussed by Siamwalla, government intervention to reduce price risk will be more difficult to sustain the larger the country's share of the commodity in the world market, the more important the commodity in the economy, the longer the period of production, and the more porous the national border.[59]

Price support or 'underwriting' is a particular form of commodity price stabilization which may be specifically aimed at mitigating farm-level risk by putting a floor under output price, while not directly restricting price above the floor level. To be most effective in terms of farm decision making, the floor price must be both guaranteed and announced before the growing season commences. Implementation is generally effected by a government standing ready to purchase at the floor price all quantities that may be offered.

Both to farmers and government, price stabilization has proved an attractive concept. In practice, difficulties arise in choosing the level at which prices are to be set, so as to gain the potential benefits of stability without, at the same time, nullifying the natural role of the market in guiding resource use. The social profitability of (even complete) price stabilization also seems modest, as documented extensively by Newbery and Stiglitz.[60] Such benefits are typically of the order of 3%, although

[57]A. Siamwalla and A. Valdes, 'Food insecurity in developing countries', *Food Policy*, Vol 5, No 4, 1980. See also B. Huddleston, D.G. Johson, S. Reutlinger and A. Valdes, *International Finance for Food Security*, Johns Hopkins University Press, Baltimore, MD, 1984.
[58]Sahn and von Braun, *op cit*, Ref 44.
[59]A. Siamwalla, 'Approaches to price insurance for farmers', in Hazell *et al*, *op cit*, Ref 55.

the caution of Kanbur as to the neglect of macroeconomic benefits of stabilization in such calculations should be borne in mind.[61]

Diversification

Another approach is to take advantage of less-than-perfectly covariate production patterns between regions in establishing production priorities. It is possible to derive an optimal pattern of regional diversification to minimize the standard deviation of production of a crop given a desired level of average output.[62] However, in seeking more risk-efficient production strategies, one may not want unduly to distort the workings of markets or violate the principles of comparative advantage, but rather only to bear the correlations in mind as a secondary factor when establishing priorities for investing public funds in agricultural research, extension, irrigation and the like. In this spirit, Tarrant has argued that a better balance in the growth of major cereal-producing regions in the USSR should be a policy consideration for the Soviets if 'regional compensation effects' are to be exploited in attaining a more stable aggregate production.[63]

Public provision of information

The quality of decision making in highly variable and risky environments depends crucially on the information available to decision makers. In the food systems of the world that are influenced by variable yields of cereals, decision makers are involved at many levels ranging from individual farms, through local marketing agents and food security administrators, regional and national authorities concerned with input and output delivery systems and food policy authorities, to international counterpart agents and interventionists. Better information is required at all these levels.

The fact of the variability of natural and economic environments explains much of existing public investment in information gathering and processing systems. If weather, production, prices, etc, were deterministic and thus easily known by all concerned, there would be little need for national meteorological services, national statistical services and interpretative research agencies such as economic forecasting agencies. As well as describing variable environments in perceptive ways that add to the stock of knowledge, such institutions can work towards further assisting decision makers by attempting to forecast uncertain futures – in the present context, droughts, frosts, pest and disease attacks, crop marketing volumes, trade volumes, flows of food aid, prices, etc. The difficulty of such work and its inherent inaccuracy do not mean that it may not be extremely valuable.[64]

The key policy issue is the extent to which existing investment, both public and private, in the provision of information is optimal. The public-good nature of much of the relevant information ensures that private investments will be much less than is socially optimal. There is, however, a dearth of research on how adequate have been the public initiatives. One thing is certain, given the diversity of level of investment around the globe, namely that, if the level in industrial countries is somewhere near socially optimal, then most developing countries are still severely under-investing. Thus, as they muster their scarce national and external resources to address developmental priorities, due attention must be devoted to easily neglected information and research and extension systems, along with the more basic infrastructural and directly productive enhancements.

[60]D.M.G. Newbery and J.E. Stiglitz, *The Theory of Commodity Price Stabilization*, Clarendon Press, Oxford, 1981.

[61]S.M.R.C. Kanbur, 'How to analyze commodity price stabilization? A review article', *Oxford Economic Papers*, Vol 36, No 3, 1984.

[62]See P.B.R. Hazell, *Instability in Indian Foodgrain Production*, Research Report 30, International Food Policy Research Institute, Washington, DC, 1982.

[63]Tarrant, *op cit*, Ref 7.

[64]D. Byerlee and J.R. Anderson, 'Risk, utility and the value of information in farmer decision making', *Review of Marketing and Agricultural Economics*, Vol 50, No 3, 1982.